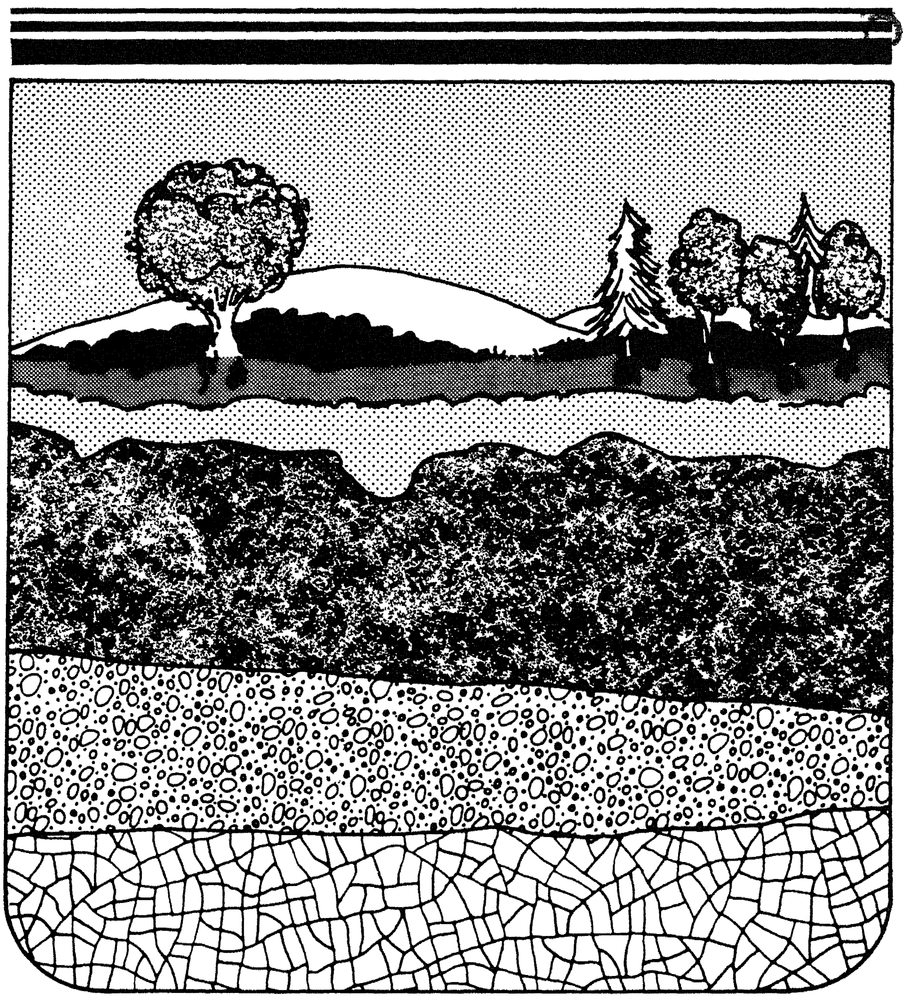
Bulletin 790

Protecting Groundwater: A Manual for Instructors



Keith S. Porter, Director
New York State Water Resources Institute
Cornell University Cooperative Extension

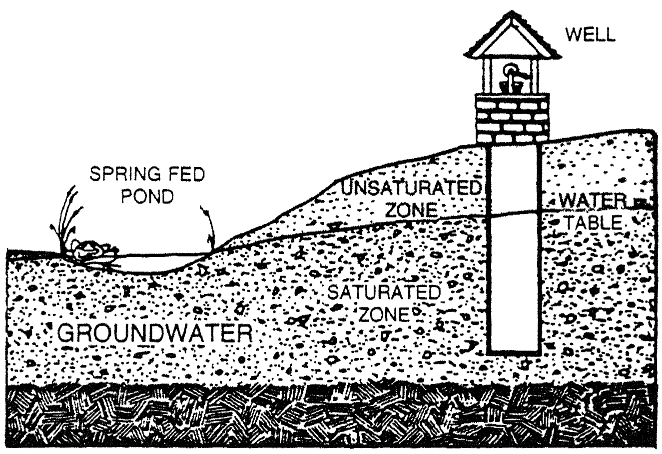
and

Michael W. Stimmann, Statewide Pesticide Coordinator
Office of Pesticide Information and Coordination
University of California Cooperative Extension

Chapter 1
Groundwater

Groundwater is the source of water for wells and springs. It is found underground, within cracks of bedrock or filling the spaces between particles of soil and rocks. The groundwater layer in which all available spaces are filled with water is called the saturated zone. The dividing line between the saturated zone and overlying unsaturated rock or sediments is called the water table (Figure 1.1). The geologic formation through which groundwater flows is called an aquifer. This can be a layer of sand, gravel, or other soil materials, or a section of bedrock with fractures through which water can flow.

Figure 1.1. Groundwater is the source of water for wells and springs.



1.1 Why Groundwater is Important

Groundwater is widely used for household and other water supplies: approximately half of the population in the United States relies on groundwater for drinking water, and more than 90 percent of rural residents obtain their water from groundwater through wells or springs.

There are good economic reasons for this widespread dependence on groundwater. In its natural state, groundwater is usually of excellent quality and can be used with no costly treatment or purification. It can be inexpensively tapped adjacent to its point of use, thereby saving the costs of transporting water long distances. In addition, costly storage facilities such as water tanks or towers are not needed. Surface water, on the other hand, usually requires storage, treatment, and transport, which are relatively expensive and difficult to manage without technical resources. For rural residents relying on individual wells and for public water supplies in some communities, groundwater often is the only available water supply. For many communities it is by far the least expensive option for public water supply systems. Consumption of groundwater is increasing at twice the rate of surface water, and this trend is expected to continue as the demand for water increases in the future. Protection of the quality of existing, and potential future, groundwater supplies therefore is an issue of vital importance.

Traditionally, groundwater has been assumed to be a relatively pristine source of water, cleaner and better protected than surface water supplies. Although nitrate and bacterial contamination were known to occur in some locations, groundwater was thought to be immune from more serious forms of pollution such as industrial discharges, hazardous waste dumps, or leaching of pesticides from agricultural operations. Within the past decade, however, a variety of pesticides and other synthetic organic compounds have been discovered in the nation's groundwater, often at concentrations far exceeding those in surface water supplies. Such discoveries have led to a new understanding of the link between what we do on the land surface and what we find in groundwater. Use, spillage, and disposal of hazardous chemicals, fertilization of lawns and crops, poorly constructed septic systems, leaky underground fuel tanks and lines, and application of pesticides all are examples of activities which can affect the quality of our groundwater supplies.

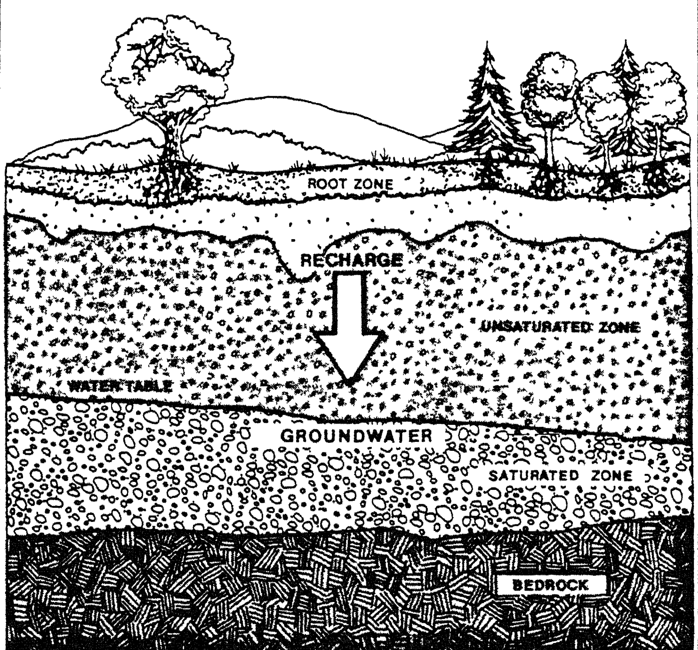
Manual

This manual focuses on protecting groundwater from pesticide contamination. However, contamination by nitrates from fertilizer use deserves mention. Fertilizers containing nitrogen can also be a major threat to groundwater in some regions of the country. Usually a crop recovers 60 percent or less of the nitrogen applied to it. In areas with light, well-aerated soils, 50 lbs. of nitrogen per acre per year, or less can be sufficient to pollute groundwater to a level above the U.S. drinking water guideline of 10 ppm (for nitrate-N). Since the rate of nitrogen application commonly exceeds 100 lbs/acre/year, the risk to groundwater is inevitably high in some areas.

1.2 Where Groundwater Comes From

Water entering the soil gradually percolates downward to become groundwater if it is not first taken up by plants, evaporated into the atmosphere, or held within soil pores. This percolating water, called recharge, passes downward through the root zone and unsaturated zone until it reaches the water table (Figure 1.2). Effective programs for protection of groundwater focus primarily on the recharge process since this controls both the quantity and the quality of water reaching the saturated zone. Water is far easier and less expensive to manage at the land surface than after it becomes less accessible and more dispersed underground.

Figure 1.2. Groundwater originates from recharge, which is water percolating downward through the soil.



The quantity and timing of recharge in any particular location depends on the amount of precipitation or irrigation, the type of soil, and the topography and geology of the site. Seasonal fluctuations occur in the quantity of recharge, leading also to fluctuations in depth to the water table. In winter and early spring when plants are not yet taking up much water, the water table may be close to or at the ground surface in humid regions. Evidence of this includes wet basements and agricultural fields that are too wet for cultivation or planting. As the summer progresses, the water table commonly drops because evaporation and plant uptake exceed recharge. During dry periods this drop may cause water shortages in shallow wells, as well as drying up of some springs, wetlands, and streams.

Both the quantity and the quality of groundwater supplies depend on the recharge water which continually filters down through the soil to the saturated zone. Chemicals on the ground surface or introduced into the soil can become groundwater contaminants if they are carried downward by this recharge water.

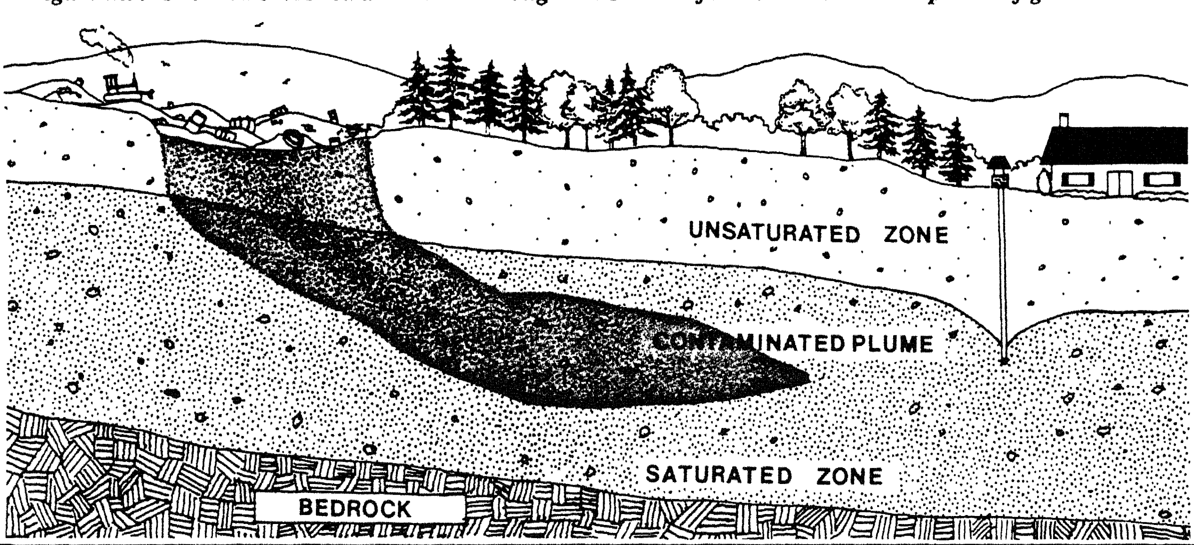
1.3 How Groundwater Moves

Groundwater does not consist of large underground lakes or streams. Rather, it is water which moves slowly through irregular spaces within rock fractures or between particles of sand, gravel, silt or clay. Whereas water in a stream may move several feet per second, groundwater may move only a few feet per month or even per year. The major exception to this general rule is in limestone areas, where groundwater may flow rapidly through large underground channels and caverns.

The geologic formation through which groundwater moves is called an aquifer. This can be a layer of sand, gravel, or other soil materials, or a section of bedrock with fractures through which water can flow. Randomly drilling a hole into the ground in many parts of the country will yield some water. Only major aquifers, though, will have sufficient flow to maintain community water systems or large irrigation wells. The quantity and quality of recharge received by aquifers depends on their depth from the ground surface, the geology of the overlying materials, and on climate, land uses, and water and chemical management practices in these recharge areas.

Recharge water moves downward through the soil until it reaches the water table. Once in the aquifer, it then travels in a more horizontal direction in response to pressure gradients within the aquifer. Eventually, groundwater resurfaces, producing springs or feeding water into wells, streams, wetlands, or other surface water bodies. Groundwater becomes contaminated when recharge water carries pollutants downward to the water table. Once in the saturated zone, these chemicals move with the groundwater, forming a region of contaminated water called a plume (Figure 1.3).

Figure 1.3. Chemicals washed downward through the soil can form a contaminated plume of groundwater.



1.4 Consequences of Groundwater Contamination

Once groundwater is contaminated, fixing the problem is difficult and may be prohibitively expensive. In 1979, for example, the pesticide aldicarb was found in Long Island groundwater. Over the next 7 years, approximately $3 million was spent measuring aldicarb concentrations in Long Island wells. Carbon filtration units were installed in over 2500 affected households at a cost of over $2.5 million, and plans were made to replace individual wells with expensive community water supply systems. These huge expenses are merely to define and treat the problem, without correcting the underlying groundwater contamination.

Another consequence of pesticide contamination of groundwater may be the imposition of restrictions on use of the pesticide. Aldicarb, for example, can no longer be used on Long Island or in parts of California, Florida, Massachusetts, New Jersey, and Wisconsin. Other compounds, such as DBCP (dibromachcloropropane) and EDB (ethylene dibromide), have been removed completely from agricultural use after their discovery in groundwater.

Cleaning up of groundwater contaminated by pesticides often is impossible, and the contaminants may last for many years. Once in groundwater, degradation of pesticides tends to be quite slow because of the cold temperatures and low microbial activity. The slow movement of groundwater means that it may take many years for the contaminated plume to flow beyond the affected wells. Even determining what wells will be affected and for how long is a difficult problem, necessitating expensive long-range monitoring to ensure the safety of drinking water supplies. Clearly, the best solution is to keep pesticides and other contaminants out of groundwater, through careful planning of storage, use, and disposal practices.

Chapter 2
Pesticide Contamination of Groundwater

Between 1950 and 1980, production of synthetic organic pesticides more than tripled in the United States, from about 400 million pounds in 1950 to over 1.4 billion pounds in 1980. Although testing for pesticides in groundwater has not been extensive, recent tests have shown a few pesticides to be significant contaminants. As of 1984, sixteen pesticides had been detected in groundwater (Table 2.1) as a result of routine agricultural use and more are likely to be found as our testing of groundwater increases. Over 80 pesticides are estimated to have the potential for movement to groundwater.

Table 2.1. Typical positive results of pesticide groundwater monitoring in the United States (After EPA, 1984)

Pesticide	Use*	State(s)	Typical Positive, ppb
alachlor	H	MD, IA, NE, PA	0.1-10
aldicarb	I, N	AR, AZ, CA, FL, MA, ME, NC,	1-50
(sulfoxide & sulfone)	H	NJ, NY, OR, RI, TX, VA, WA, WI	
atrazine	H	PA, IA, NE, WI, MD	0.3-3
bromacil	H	FL	300
carbofuran	I, N	NY, WI, MD	1-50
cyanazine	H	IA, PA	0.1-1.0
DBCP	N	AZ, CA, HI, MD, SC	0.01-20
DCPA (and acid products)	H	NY	50-700
1,2-Dichloropropane	N	CA, MD, NY, WA	1-50
dinoseb	H	NY	1-5
dyfonate	I	IA	0.1
EDB	N	CA, FL, GA, SC, WA, AZ, MA, CT	0.05-20
metolachlor	H	IA, PA	0.1-0.4
metribuzin	H	IA	1.0-4.3
oxamyl	I, N	NY, RI	5-65
simazine	H	CA, PA, MD	0.2-3.0

*H = herbicide, I = insecticide, N = nematicide.

Most farm families rely on individual wells, untreated, unmonitored, and located close to fields on which pesticides are applied. Water feeding these wells is likely to contain whatever pesticides have been leached from the fields by recharge waters. But not all pesticides will leach, and certainly not all farm wells are contaminated. An understanding of what causes these differences is crucial in protecting the quality of rural groundwater supplies.

Which pesticides will leach, and in what quantities, depends in part on the amount applied per acre per year, the solubility of the compound, how strongly it is held by the soil, and how quickly it breaks down in the root zone. Before the 1940's, most pesticides were compounds of arsenic, mercury, copper, or lead. Although these compounds may have made their way into drinking water, they were not highly soluble, and the residues ingested in contaminated fruits and vegetables were of far greater concern. Synthetic organic pesticides were introduced during World War II and were thought to be far safer and more effective. These included chlorinated hydrocarbons such as DDT, aldrin, dieldrin, chlordane, heptachlor, lindane, endrin, and toxaphene. Because of their low solubility in water and their strong tendency to chemically attach to soil particles, these compounds have rarely contaminated groundwater. Although when introduced, they were thought to be safe to humans and the environment, they later were discovered to accumulate in the environment and build up to toxic concentrations in food chains. Use of most of the chlorinated hydrocarbon pesticides consequently has been either restricted, suspended, or cancelled.

One group replacing the chlorinated hydrocarbons has been the organophsophorus compounds such as malathion and diazinon. Although some organophosphorus compounds are highly toxic to humans, they generally break down rapidly in the environment and rarely have been found in groundwater. Another group replacing the chlorinated hydrocarbons are carbamate pesticides including aldicarb, carbofuran, and oxamyl. These compounds tend to be soluble in water and weakly adsorbed to soil. Consequently, if not degraded in the upper soil layers, they have a tendency to migrate to groundwater. The most significant occurrences of groundwater contamination have been with the carbamate pesticides.

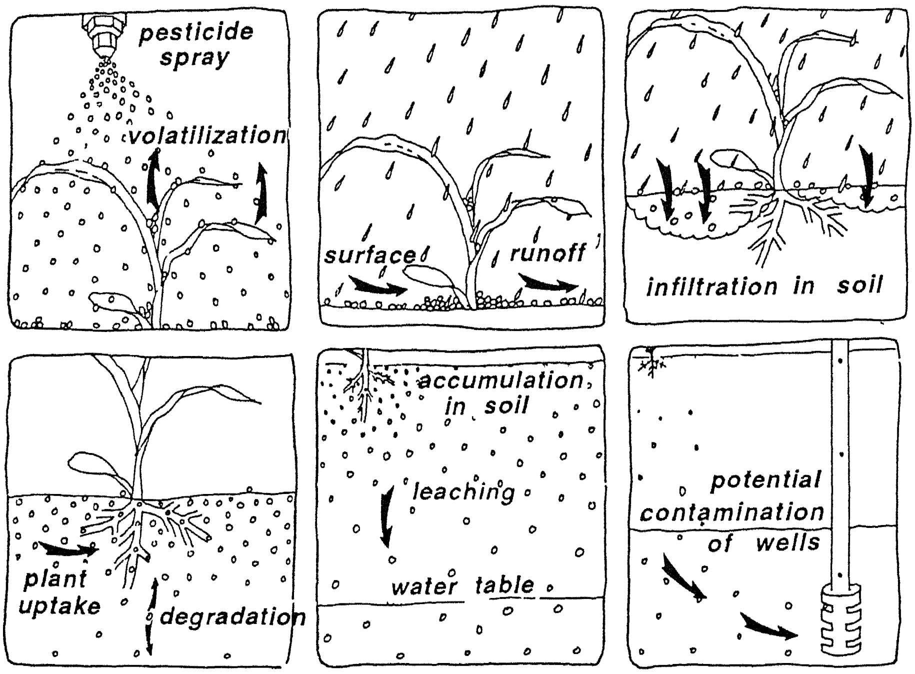
After a pesticide is applied to a field, it may meet a variety of fates (Figure 2.1, next page). Some may be lost to the atmosphere through volatilization, carried away to surface waters by runoff, or broken down in the sunlight by photolysis. That which enters the soil may be taken up by plants, degraded into other chemical forms, or leached downward, possibly to groundwater. The remainder is retained in the soil and continues to undergo these processes. How much meets each of these fates depends on many factors, including:

- the properties of the pesticide,
- the properties of the soil,
- the conditions of the site, and
- management practices.

2.1 *Pesticide Properties*

The U.S. Environmental Protection Agency has developed a list of threshold values for some key chemical and physical properties of pesticides (Table 2.2, next page). Compounds with properties beyond any of these threshold values warrant extra attention with regard to their potential for leaching to groundwater. These values, however, are only a rough guide and pesticides outside of the threshold values may leach to groundwater. Aldicarb, for example, has an estimated K_d of 10 but has been found in groundwater.

Figure 2.1. Potential environmental fates of applied pesticides



2.1.1 *Water Solubility*

The first of these threshold values is solubility, the tendency of the pesticide to dissolve in water. The higher the solubility, the greater the tendency of the compound to be washed downward through the soil, possibly leaching to groundwater.

2.1.2 *Volatilization*

Vapor pressure is a measure of the tendency of a compound to become a gas. The higher the vapor pressure of a pesticide, the faster it is lost to the atmosphere. This does not necessarily mean, however, that pesticides with high vapor pressures pose no threat to ground-

Table 2.2. Threshold values indicating potential for groundwater contamination by pesticides (from U.S. Environmental Protection Agency. 1986. Pesticides in Groundwater: Background Document).

Chemical or Physical Property	Threshold Value
Water Solubility	greater than 30 ppm
Henry's Law Constant	less than 10-2 atm-m-3 mol
K_d	less than 5, usually less than 1 or 2
K_{oc}	less than 300 - 500
Speciation	negatively charged, fully or partially at ambient pH
Hydrolysis Half-Life	greater than 25 weeks
Photolysis Half-Life	greater than 1 week
Field Dissipation Half-Life	greater than 3 weeks

water. To the contrary, several highly volatile pesticides including EDB, DBCP, and DCP are common groundwater contaminants. One factor affecting how much volatilizes is the mode of application. These pesticides are injected into the soil, so their contact with the atmosphere is limited. Another factor is the relationship between the compound's volatility and its solubility, because highly soluble compounds may be washed into the soil before they have a chance to volatilize.

The second value in Table 2.2, the Henry's Law Constant (H), provides a measure of the susceptibility of a pesticide to volatilize, based on both its vapor pressure and its solubility:

$$H = \frac{\text{vapor pressure}}{\text{solubility}}$$

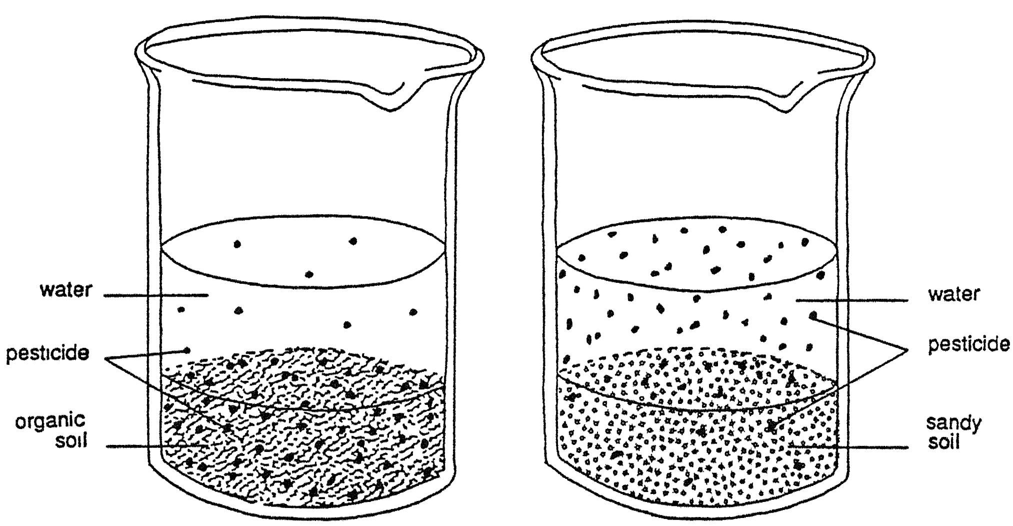
The lower the value of the Henry's Law Constant, the higher the susceptibility of a pesticide to leaching. Examples of pesticides with a high value for H and thus low leaching potential include trifluralin, triallate, phorate, EPTC, and dieldrin.

2.1.3 Adsorption

The tendency of a pesticide to leach also depends on how strongly it adsorbs to soil particles. Pesticides which are adsorbed onto soil particles are kept from moving to groundwater and remain in the root zone where they are availalbe to plants and may eventually be degraded. Adsorption refers to the attraction between a chemical and the soil particles. Compounds which are strongly adsorbed onto soil are not likely to leach, regardless of their solubility. Compounds which are weakly adsorbed, on the other hand, will leach in varying degrees depending on their solubility. The strength of sorption is a function of the chemical properties of the pesticide, but also depends on the soil type and amount of soil organic matter present. The third and fourth threshold values listed in Table 2.2, K_d and K_{oc}, provide measures of pesticide adsorption on soils.

The adsorption partition coefficient (K_d) is determined by mixing soil, pesticide, and water, then measuring the concentration of pesticide in solution after equilibrium is reached (Figure 2.2). The adsorption coefficient then can be calculated as the ratio of pesticide con-

Figure 2.2. K_d is calculated using measurements of pesticide distribution between soil and water. Organic soils retain more pesticide than do sandy ones.



centration in the adsorbed state to that in solution:

$$K_d = \frac{\text{concentration adsorbed}}{\text{concentration dissolved}}$$

A wide range exists in pesticide partition coefficients, for example:

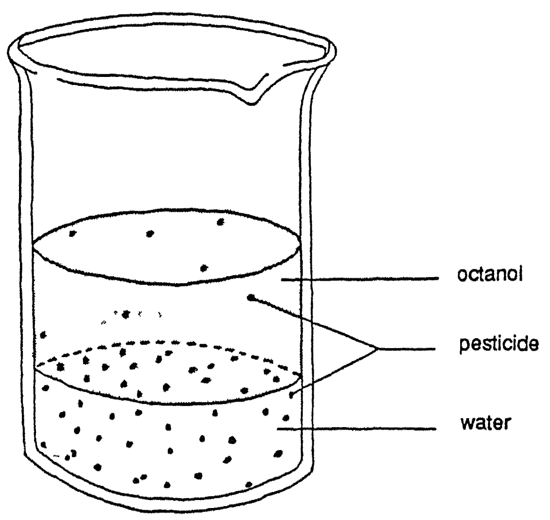
Pesticide	K_d
Aldicarb	10
Carbofuran	29
Atrazine	172
Carbaryl	229
Malathion	1,178
Parathion	7,161
DDT	243,000

It is easy to see from this list why aldicarb and atrazine have been found in groundwater in many agricultural areas, while DDT has not.

The major drawback of using K_d to predict leaching of pesticides is that it is highly dependent on soil type. However, it has been found that the single most important soil variable determining pesticide retention is the organic matter content. It therefore is useful to adjust the K_d value by the percent organic carbon in the soil, yielding another adsorption coefficient, K_{oc}, which is relatively independent of soil type:

$$K_{oc} = \frac{K_d}{\text{\% organic carbon in soil}}$$

Figure 2.3. K_{ow} is calculated using measurements of pesticide destribution between octanol and water.



There is yet another coefficient which approximates K_{oc} but is easier to measure. This is the octanol/water partition coefficient (K_{ow}). This number is obtained by measuring the distribution of the pesticide between octanol (an alcohol) and water after equilibrium is reached (Figure 2.3). The octanol/water partition coefficient also is useful in predicting whether a pesticide will accumulate in animal tissues, as do DDT and other chlorinated hydrocarbons.

2.1.4 Speciation

Speciation refers to the electrical charge on chemical compounds. The organic matter and clay in soils tend to be negatively charged. Positively charged chemicals cling to these negatively charged soil particles. Chemicals with a negative charge are more mobile in soil because the like charges are repelled. The greatest potential for leaching therefore occurs in negatively charged pesticides, and in soils which are low in clay and organic matter content.

2.1.5 Degradation

The final three threshold values listed in Table 2.2 are measures of a pesticide's rate of degradation, or chemical breakdown. The longer the compound lasts before it is broken down, the longer it is subject to the forces of leaching.

One process through which pesticides degrade is hydrolysis, the reaction of a chemical with water. Another is photolysis, or breakdown caused by exposure to sunlight. Both of these can be measured through laboratory experiments. A third major pathway by which pesticides degrade is through oxidation and other reactions mediated by microorganisms in the soil.

The natural distribution of microbes in the soil ecosystem has important implications for managing pesticides. The vast majority of microbes live in the uppermost parts of the soil. If a chemical leaches below the root zone, it will encounter far fewer microbes by whose actions it may be degraded. Therefore, if a pesticide persists long enough to move below the root zone, it is a candidate leacher.

The final value in Table 2.2, the field dissipation half-life, is an overall empirical estimate of the length of time in which half of the original amount of the pesticide to degrade to other chemical forms, through physical, chemical, and microbiological processes. The longer the half-life, the greater the opportunity for the pesticide to be transported to groundwater. Half-life is difficult to predict because it varies widely for each compound and soil condition. Factors affecting half-life include:

- soil type
- soil temperature
- soil moisture content
- concentration of the chemical
- method of application
- chemical structure, and
- amount of sunlight.
- microbial populations

Although half-life estimates area useful empirical measure of a key aspect of pesticides in soil, their use requires caution. If a pesticide is degraded mainly by microbial action, then the presence of microbes will determine the rate of degradation. For example, there are usually far fewer microbes in sub-soils. Therefore, half-life values in the sub-soil could be significantly longer than those measured in the root zone.

In general, degradation proceeds faster as the soil becomes wetter, but the changes in half-life are not consistent from one soil to another. Because of the many variables involved, prediction of half-life in the field or from experiments in the lab is an inexact science.

2.2 Soil Properties

Many soil characteristics affect leaching; the principles ones include:

- soil texture,
- soil permeability,
- soil organic matter content, and
- soil structure, including macropores.

Soil texture is determined by the relative proportions of sand, silt, and clay. Texture affects movement of water through soil, and therefore also movement of dissolved chemicals such as pesticides. The coarser the soil, the faster the movement of percolating water, and the less opportunity for adsorption of dissolved chemicals. Soils with more clay and organic matter tend to hold water and dissolved chemicals longer. These soils also have far more surface area on which pesticides can be adsorbed. The coarser-textured the soil, therefore, the greater the chance of the pesticide reaching groundwater.

Soil permeability is a measure of how fast water can move downward through a particular soil. Water moves quickly through soils with high permeability, so frequent irrigation may be necessary. They also lose dissolved chemicals with the percolating water. In highly permeable soils, therefore, the timing and methods of pesticide application need to be carefully designed to minimize leaching losses.

Soil organic matter influences how much water a soil can hold, and how well it will be able to adsorb pesticides. Increasing the soil's organic content, through practices such as application of manure or plowing under of cover crops, increases the soil's ability to hold both water and dissolved pesticides in the root zone where they will be available to plants and to eventual degradation.

Soil structure, the way soil particles are aggregated, will also affect water movement. Sometimes large openings (macropores) resulting from physical processes such as animal borings or freeze/thaw action may be present in fine-textured soils. Under certain conditions, macropores result in rapid water movement through even these fine-textured soils.

2.3 Site Conditions

Conditions of the site also affect the potential for reaching groundwater. These include:

- depth to groundwater
- geologic conditions, and
- climate and irrigation practices.

2.3.1 Depth to Groundwater

The shallower the depth to groundwater, the less soil there will be to act as a filter. Also, there will be fewer opportunities for degradation or adsorption of pesticides. Extra precautions therefore need to be taken to protect groundwater in areas where it is close to the ground surface. In humid regions, groundwater may be only a few feet below the surface of the soil. If rainfall is high and soils are permeable, water carrying dissolved pesticides may take only a few days to percolate downward to groundwater. In arid regions, groundwater may lie several hundred feet below the soil surface, and leaching of pesticides to groundwater may be a much slower process.

The depth to groundwater does not remain constant over the course of the year. It varies according to the amount of precipitation and irrigation, whether the ground is frozen, and how much groundwater is being withdrawn by pumping. Spring and fall generally are the times of greatest recharge and, therefore, also of highest water table elevations. Groundwater levels tend to go down in summer when evaporation and plant uptake are high, and in winter if recharge is hampered by frozen soils. Such fluctuations in recharge quantities can have consequences for recharge quality as well. If spring rains come shortly after application of pesticides, for example, large quantities of the chemicals may be transported downward to groundwater, which at that time of year is likely to be relatively close to the ground surface

2.3.2 Geologic Conditions

In addition to depth to groundwater, it is important to look at the permeability of the geologic layers between the soil and groundwater. Highly permeable materials, such as gravel deposits, allow water and dissolved pesticides to freely percolate downward to groundwater. Layers of clay, on the other hand, are much less impermeable and thus inhibit the movement of water. Groundwater quality is most vulnerable in areas where permeability of geologic layers is rapid.

Regions with limestone deposits are particularly susceptible to groundwater contamination because water may move rapidly through dissolved caverns, receiving little filtration or chance for chemical degradation reaching groundwater.

[**Optional:** Regional inserts about vulnerable geologic conditions, such as limestone areas or areas of rapid permeability.]

2.3.3 Climate and Irrigation Practices

Areas with high rates of rainfall or irrigation may have large amounts of water percolating through the soil, and therefore a high susceptibility to leaching of pesticides, especially if the soils are highly permeable. This is particularly true if high rainfall or heavy irrigation coincides with or follows shortly after the application of agricultural chemicals thus washing them below the root zone.

2.4 Management Practices

Another factor determining leaching potential is the way in which a pesticide is applied. Injection or incorporation into the soil, as in the case of nematicides, makes the pesticide most readily available for leaching.

The rate and timing of pesticide application are also critical in determining whether it will leach to groundwater. The larger the amount used, and the closer the time of application to a time of heavy rainfall or irrigation, the more likely that substantial amounts of the pesticide will be lost to groundwater. Particular care should be taken when practicing chemigation to prevent pesticides from being carried downward through the soil by the percolating irrigation water and to prevent back-flow into the water source. When practicing chemigation, only the amount of water needed to activate the pesticide should be used.

2.5 Determining Leaching Potential

Whether or not a pesticide will reach groundwater depends on many factors, including its chemical properties, the soil type, the depth to groundwater, and the way in which the pesticide is applied (Table 2.3). By combining all of these factors, we can determine which areas and practices show the greatest vulnerability to pesticide contamination of groundwater.

Consultation with local Soil Conservation Service and Cooperative Extension agents may provide information and assistance in designing a program for controlling pests without threatening the quality of underground water supplies.

Greatest care needs to be taken with pesticides that are highly soluble, do not adsorb strongly to soil particles, and persist for a long time in the soil. The Environmental Protection Agency has established a list of such pesticides, called "suspected leachers," for which extra precautions should be used to prevent contamination of groundwater supplies. Some of these "suspected leachers" are listed in Table 2.4.

Table 2.3. Factors indicating greatest vulnerability to leaching of pesticides.

pesticide properties

* high solubility
* low adsorption
* persistent

soil characteristics

* sand and gravel
* low in organic matter

site conditions

* shallow depth to ground water
* wet climate, or extensive irrigation

management practices

* pesticide injection or incorporation into soil
* poor timing

Table 2.4. Some pesticides suspected to be susceptible to leaching to Groundwater

Chemical Name	Found in Groundwater (1984)
Acifluorfen	
Alachlor	x
Aldicarb	x
Ametryn	
Atrazine	x
Bromacil	x
Carbofuran	x
Chloramben	
Cyanazine	x
Dalapon	
DBCP	x
Dacthal/DCPA	x
1,2-dichloropropane	x
Dinoseb	x
Disulfoton	
EDB	x
Fenamiphos (Nemacur)	
Fluometuron	
Hexazinone	
Methomyl	
Metolachlor	x
Metribuzin	x
Oxamyl	x
Picloram	
Prometone	
Pronamide	
Propazine	
Simazine	x
Tebuthiuron	
Terbacil	

Chapter 3

Applicator Practices

Prevention is the best way to minimize groundwater contamination. Proper application practices when followed can make pesticide use more efficient and help prevent groundwater contamination.

3.1 Applicator Practices

3.1.1 The need, method, and frequency of chemical control should be evaluated in the context of potential groundwater contamination.

Pesticides should only be used when and where necessary and only in amounts adequate to control pests. Using pesticides only when necessary and using only the minimum amount consistent with effective pest management will minimize potential groundwater contamination.

Multiple applications of a single pesticide to the same site, even when applied according to label directions have caused groundwater contamination in several locations in the U.S. Growers who depend on continual applications of the same pesticide over long periods should evaluate their pest management practices carefully. Reducing the number of applications (and the total amount applied), changing to a pesticide that is less likely to move through the soil, or using alternative methods of pest control can help to minimize groundwater contamination.

3.1.2 The susceptibility of the particular soil type to leaching should be determined prior to using pesticides with the potential to contaminate groundwater.

Pesticides can reach groundwater by moving through the soil. Some pesticides move readily through soils that are well-drained, sandy, or low in organic matter. Sandy soils have low water-holding capacity, support smaller populations of microorganisms which can break down pesticides, and lack clay and organic matter to bind the chemicals. Because of these factors, the possibility of groundwater contamination is greater when pesticides are applied to sandy soil than to any other soil type.

3.1.3 The location of the pesticide application should be considered in relation to ground- and surface-water.

Pesticides should not be applied where they can reach ground- or surface-water sources. The closer the water table is to the surface of the soil, the greater the possibility for contamination. As an example, land that is near a marsh most likely has a water table that is close to the surface. In general, pesticides should not be handled or applied within 25-50 feet of a well.

3.1.4 In an effective pest management program, pesticides should be selected that are less likely to leach.

The potential of an agricultural chemical to move in the soil varies according to the nature of the chemical, the properties of the soil, and the agricultural practices used. Based on these factors, the EPA has identified certain pesticides that are suspected as having the greatest potential for leaching into groundwater (Figure 2.4).

The most significant cases of groundwater contamination have involved herbicides, nematicides and carbamate pesticides. These compounds tend to be soluble in water and are weakly absorbed to soil. Carbamates have a tendency to migrate to groundwater if they are not degraded in the upper soil levels. Another pesticide group, the organophosphates, generally break down rapidly in the environment and rarely have been found in groundwater. Whenever possible, the pesticide applicator should select a non-carbamate pesticide that is less likely to leach and reach the groundwater. The Cooperative Extension Service or USEPA can provide information on the leaching potential of different pesticides.

3.1.5 Follow the directions on the pesticide label.

The pesticide label is designed to provide the applicator with useful and important information in order to use the pesticide efficiently, safely, and legally. There are four times when the pesticide label should be read: before the pesticide is purchased, before the pesticide is mixed and applied, before the pesticide is stored, and before disposing of the pesticide or container.

Pesticide labels contain the following information: the brand name, common name, type of formulation, ingredient statement, net contents, name and address of manufacturer, EPA registration and establishment number, statement of use classification (general or restricted-use), signal words (danger, poison, warning, caution) and symbols (skull and cross bones), precautionary statement, statement of first aid, directions for use, misuse statement, reentry information, storage and disposal directions, residues, and restrictive statement. An increasing number of pesticide labels also contain information on avoiding groundwater contamination.

There are both civil and criminal penalties for using a pesticide in a manner which conflicts with the label.

3.1.6 Only apply pesticides at the right time

Fewer pesticide applications are required if they are carefully timed in relation to pest problems, crop growth, irrigation, and rainfall. Pest populations should be monitored to determine the proper time of application. Because irrigation and rain can affect the leaching potential of some pesticides, irrigation schedules and weather forecasts should be considered when determining the timing of pesticide application.

3.1.7 Pesticides should be measured carefully.

Groundwater contamination can be minimized by staying within recommended label rates. Using more product than the label recommends will not do a better job of controlling pests. It only increases the cost of pest control, the resistance of pests to chemical control, and the chances that the pesticide may reach the groundwater. Rough approximations generally lead to over-application of the pesticide and increase the risk of contaminating the groundwater.

3.1.8 Application equipment should be properly calibrated and maintained.

It is important to calibrate application equipment to ensure that the correct amount of pesticide is applied evenly throughout the field. Properly calibrated equipment reduces the chances of applying too much pesticide. If too much pesticide is applied in one spot, normal degradation processes are hindered leaving more pesticide residue which may contaminate groundwater. Application equipment should be checked regularly for leaks, malfunctions, and calibration.

3.1.9 Pesticide spills and back-siphoning should be avoided.

A pesticide that is spilled on the ground or near water sources, such as wells or streams, has the potential of moving over or through the soil and reaching the groundwater.

Spills can occur from poorly maintained application equipment. The valves on application equipment should be checked for leaks or damage and replaced as necessary. Backflow devices (check values or air gaps) should be installed on the filling pipe between the water source and the application equipment. These devices prevent the pesticide-contaminated water from backflowing into the water source. Overfilling the spray tank may result in spills.

3.1.10 Applicators should direct pesticide applications to the target site.

Applicators should avoid overspraying the ground to prevent the possible introduction of the pesticide into the groundwater. Applications that are effectively directed to the target will reduce drift and are less likely to contaminate water sources.

3.1.11 Pesticides should be properly disposed.

The best precaution against pesticide disposal problems is good planning. This begins with buying and mixing the right amount of pesticide.

After the pesticide application is complete, the applicator should take care in disposing of the excess pesticide and the pesticide container. Follow the label for proper pesticide disposal to avoid groundwater contamination. Pesticide containers should be triple-rinsed or pressure-rinsed (to prepare them for disposal), the rinse water poured back into the spray tank and used to treat the site or crop away from any water souces such as a well.

3.1.12 Pesticides should be stored safely.

The law requires that pesticides be stored in a safe, secure, and well-identified place. Pesticides must always be stored in the original, labelled container with the label clearly visible. Pesticides should be stored in a cool, well ventilated location away from wells, pumps, or other water sources. Pesticide containers should be tightly sealed and periodically checked for leakage, corrosion breaks, tears, etc.

3.1.13 The pesticide applicator should maintain records of pesticides that were used.

Information from these records may help to prevent future contamination of the groundwater and help protect the applicator should questions about treatments arise in the future.

3.2 Additional Groundwater Protection Methods

Additional protection methods, such as carefully timing irrigation, avoiding over irrigation, proper use of chemigation, and inspecting wells, can be used to prevent groundwater contamination of pesticides.

3.2.1 Time irrigation

If it is practical, irrigation should be delayed for one or more days after a pesticide application. A delay in irrigation gives the plant and the soil more time to take up the pesticide. This reduces the amount of pesticide that is available for movement through the soil with irrigation. Thus, the chances of the pesticide reaching the groundwater are reduced.

3.2.2 Avoid over irrigation

Good irrigation management that emphasizes using the proper amount of irrigation will reduce soil erosion and decrease the chances of the pesticide entering into the surface and groundwater. Extra care should be taken when irrigating and applying pesticides on clay soils because they are especially susceptible to run-off.

3.2.3 Chemigation

Particular care should be used when practicing chemigation. Irrigation may carry pesticides downwards through the soil into groundwater. Use only the amunt of water needed to activate the pesticide. Devices should be used to prevent possible back-flow of the pesticides into the water supply. Materials used in pumps and seals should be compatible with chemicals being injected. Unattended chemigation systems should be checked frequently to avoid groundwater contamination and other problems.

3.2.4 Wells should be inspected to prevent groundwater contamination.

A well acts as a direct pipeline to groundwater. Groundwater can become contaminated if pesticides or other pollutants enter a well directly from the surface, through openings in or beneath a pump base, or through soil adjacent to the well.

New wells, if properly constructed, can prevent groundwater contamination. For example, wells should be located away from pollution sources likely to contaminate the well. Proper seals between the pump and the pump base help prevent the entry of contaminants. Seals between the casing of the well and the wall of the hole can prevent water near the soil surface from entering the well and possibly contaminating the groundwater.

Proper maintenance of existing wells helps prevent groundwater contamination. Wells and pumps should be inspected regularly for leaks and to insure that the seal is adequate to prevent pesticides from entering the groundwater. Irrigation pipes should also be checked for leaks that could lead to contamination of the groundwater.

3.3 Integrated Pest Management

Integrated Pest Management (IPM) is an alternative to chemical pest control. IPM is the integrating of available pest control techniques in a manner which is economically and ecologically sound. IPM uses scientifically sound strategies, such as economic thresholds and field monitoring, to determine the proper timing of pesticide applications. Economic threshold is defined as the pest population level that produces damage equal to the cost of preventing that damage. Field monitoring, by trapping or other sampling devices, can determine whether existing pest populations are at economic threshold levels that warrant the use of pesticides or other control methods.

IPM encourages beneficial organisms such as predators, parasites, and pathogens as a natural means of control. In an IPM program, pesticides are used only when field monitoring indicates that they are needed to prevent eventual crop losses. Some examples of IPM are using pesticides that do not harm beneficial organisms, monitoring pest populations to properly time pesticide applications, and using cultural methods such as crop rotation and delayed planting in conjunction with minimal pesticide applications.

Some IPM programs have successfully eliminated unnecessary pesticide applications and reduced the total number of applications in a season. This has resulted in reduced pest control costs and it may prevent adverse effects such as pest resurgence, secondary pest outbreaks, and pesticide resistance. Furthermore, because of the reduced need for pesticides, groundwater contamination by pesticides is less likely to occur.

There are many examples of successful IPM programs in the United States. Two such examples are IPM on tobacco in North Carolina and on tomatoes in California. By using traps to monitor the tobacco budworm, growers have been able to time their pesticide applications more precisely. This effort, combined with early stalk destruction to reduce winter carry-over of the budworm, has resulted in more than a 50% decrease in pesticide use against the budworm.

In California, an IPM program was introduced to reduce damage to processing tomatoes by the fruitworm and beet armyworm. The program provides growers with a probability-based field sampling method and decision rules for insecticide spraying based on the sample results. By using the tomato IPM program, growers increased their net returns about $7.00 per acre and used 20% less insecticide.

Various estimates suggest that the adoption of the currently available IPM practices would permit a 40-50% reduction in the use of insecticides within a 5-year period. A reduction of 70-80% is envisioned in the next 10 years. Many pest management experts believe that these reductions are possible with no resulting sacrifice in crop yield or grower profit and at the same time providing an additional method of preventing groundwater contamination.

Most groundwater contamination problems are associated with soil-dwelling pests such as nematodes, weeds, pathogens and insects. Thus, IPM programs that would be especially important in reducing groundwater contamination would be those incorporating the use of rotation, fallowing, solarization, resistant cultivars, and less persistant pesticides. For example, studies have shown that cotton yields in California are as high in nematode-infested fields following a rotation with resistant tomato cultivars as after a preplant soil fumigation treatment.

Chapter 4

Health Effects of Groundwater Contamination

The contaminants most likely to show up in groundwater are bacteria, nitrates, some common minerals such as calcium and magnesium, and agricultural pesticides. The presence of chemicals and other contaminants in groundwater may present a risk to public health. The impact of pesticide-contaminated groundwater on human health is still being assessed and many questions remain about chronic health impacts. As information becomes available, EPA will continue to establish health standards and guidelines for pesticides.

4.1 Dose-Response Relationship

Potential harmful human health effects of agricultural pesticides in groundwater depend upon the nature of the chemical contaminant, the concentration of the particular pesticide in the groundwater, and the frequency as well as the duration of human exposure. For example, a highly toxic chemical such as aldicarb may cause acute health effects in very small concentrations; whereas a less toxic material such as methoxychlor (which is 5000 times less toxic than aldicarb) may only cause health effects when high concentrations are present. This is referred to as a dose-response relationship.

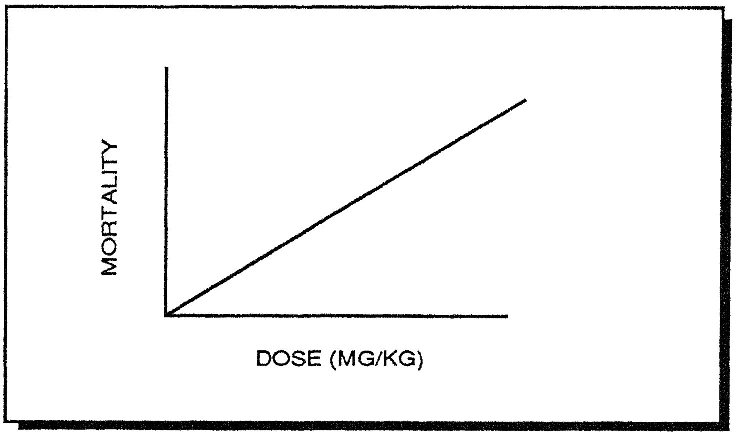
The dose-response relationship is the most fundamental concept in environmental toxicology (Figure 4.1). The relationship includes the assumptions that (1) the response is a function of the concentration at the site, (2) the concentration at the site is a function of the dose, and (3) the response depends on the dose. An understanding of the dose-response relationship is essential when discussing the health effects of toxic substances.

The concentration of a pesticide found in groundwater depends on the amount of pesticide that reaches the soil surface, the way it travels within the particular soil, and how fast the chemical is degraded. For example, a high application rate may lead to a high concentration of a pesticide in the soil; then, if the pesticide is slow to breakdown in the soil, it may eventually contaminate nearby groundwater.

4.2 Types of Health Effects

Once a pesticide reaches groundwater and enters a drinking water system, it may have an effect on human health. The human health effects of pesticides have two aspects. Acute toxicity, or immediate effects, resulting from short-term exposure can cause symptoms such as chemical burns, nausea, or convulsions. Chronic toxicity comes from more prolonged exposures and can

Figure 4.1. Dose-response relationship.



result in effects such as birth defects, cancer, and nerve damage. Pesticides in groundwater are normally not present in concentrations high enough to cause acute health effects. However, pesticides in small amounts may cause chronic effects.

Because pesticides typically occur in trace amounts in groundwater and people may be exposed to these pesticides over a long period of time, we are concerned primarily with their potential for causing chronic health problems. The type and severity of any health effects from chronic exposure to pesticides depend on the type and amount of pesticide substances ingested. Health effects also depend on how quickly the chemical is metabolized and excreted from the body.

Exposure to a harmful substance may have either reversible or irreversible health effects. Effects such as headaches and stomach aches are reversible, while cancer, birth defects, and some kinds of damage to the nervous system are examples of irreversible effects. Depending upon the body's reaction to the substance, reversible and/or irreversible effects can result from short term or long term exposure.

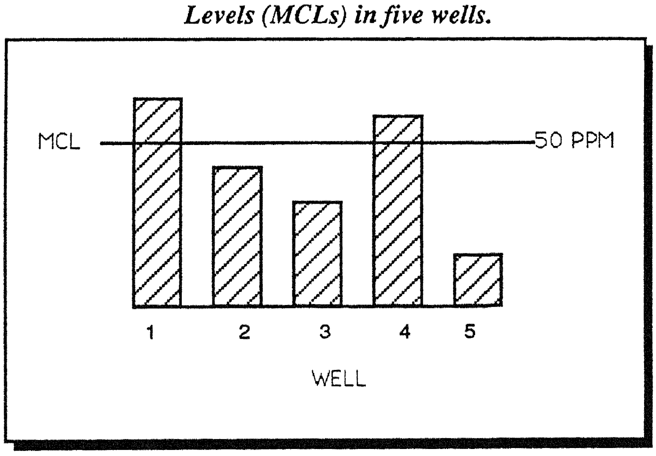
4.3 Assessing the Safety of a Pesticide

In assessing the safety of a pesticide, it is necessary to have a method of accurately estimating and expressing toxicity. Public agencies responsible for protecting groundwater and public health, such as the EPA, have established guidelines and standards for some of the pesticides that have already been found in groundwater.

4.3.1 Maximum Contaminant Levels (MCLs)

The EPA has established standards, called Maximum Contaminant Levels (MCLs), for certain pesticides in public water supplies. MCLs are used to define action levels when chemicals are found in drinking water. If chemicals are detected in the water, action should be taken to find and eliminate the source of the chemicals. If the concentration of a chemical is above the established MCL, the water supply cannot be used. Decontamination treatment must be provided or an alternate water supply used (Figure 4.2). If the chemical concentration remains below the action level, the water supply may continue to be used while the source of the chemicals should be investigated and measures taken to prevent its continued introduction into the water. MCLs are standards that can be legally enforced: for example, contaminated wells can be ordered to shut-down and enforcement actions taken against the polluter. Guidelines have been developed for some pesticides that do not currently have a MCL standard. As more complete information on long term health impacts is developed, additional MCLs and guidelines will be written. Further information on MCLs can be obtained from the EPA.

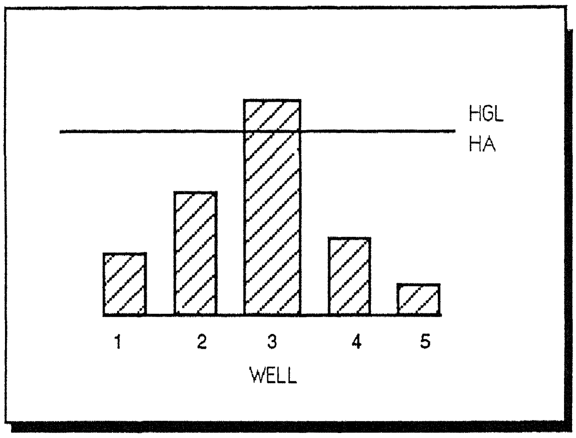
Figure 4.2. An example of Maximum Contaminant Levels (MCLs) in five wells.



4.3.2 Health Guidelines

The EPA also has a set of non-enforceable health guidelines, called Health Advisories (HAs) and Health Guidance Levels (HGLs). In the event that a MCL has not been set, Health Advisories and Health Guidance Levels are used to help state and local officials evaluate the health significance of chemicals that have been found in the groundwater. HAs and HGLs are the minimum chemical concentrations at which adverse health effects are to be anticipated (Figure 4.3).

Figure 4.3. An example of Health Advisories (HAs) and Health Guidance Levels (HGLs) in five wells.



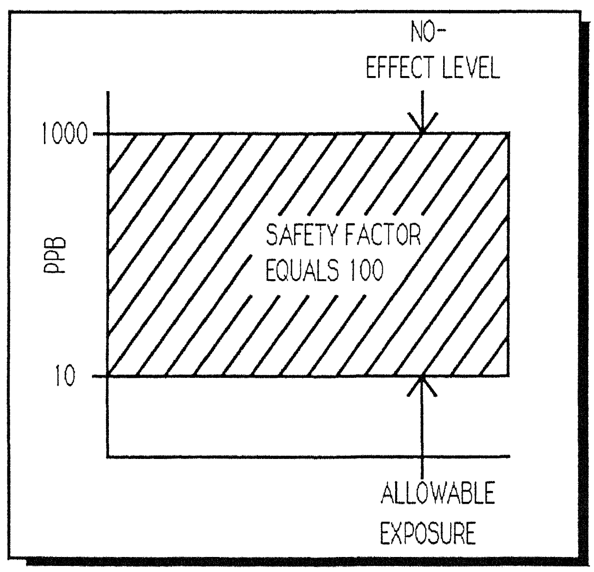
These are revised as new information becomes available.These health standards and guidelines are generally based on tumor, birth defect, and cancer studies performed on laboratory rats and mice. Even for pesticides which have been thoroughly studied, some uncertainty still exists in estimating the potential health effects of chemicals found in groundwater. Uncertainties can arise because of lack of complete toxicity data on the chemicals. Uncertainties can also arise because it is difficult to make useful comparisons between short-term studies done on laboratory animals and exposure to groups of humans exposed over long periods and living in complex environments.

In developing state and federal water contamination standards, a safety factor is used to compensate for these uncertainties. This helps assure that human exposures are not likely to lead to any significant adverse health effects. The safety factor is determined by the amount of uncertainty in the experimental data. If the results from an experiment are conclusive and indicate that there is a potential health effect, then a safety factor of 100, for example, may be chosen (Figure 4.4). However, if data is lacking or inconclusive, the safety factor could be increased to as much as several thousand.

It is important to understand that the potential for groundwater contamination depends upon the properties of the pesticide used and the method of application as well as such factors as soil characteristics, depth of the water table, amount of irrigation, and climate.

To protect human health, pesticides should be kept out of the groundwater. The best way to minimize groundwater contamination is to prevent pesticides from reaching the groundwater. Pesticide applicators can help to prevent groundwater contamination by choosing pesticides with the least potential for leaching into the groundwater and by using pesticides carefully, following the label, avoiding spills, and by using proper disposal methods.

Figure 4.4. An example of safety factors.



Chapter 5

Laws and Regulations

Federal, state, and local laws and regulations are intended to provide protection of our drinking water and groundwater. The legal consequences of the presence of pesticides in groundwater are governed by the most comprehensive laws and regulations developed for any single class of chemicals. Sixteen different federal laws contain provisions to protect groundwater from agricultural chemicals. Seven major federal acts are applicable to groundwater contamination by pesticides. These are:

1. *The Clean Water Act, (CWA)*

   This act gives EPA jurisdiction over groundwater quality. The objective of the act is to clean-up the nation's water and make it unpolluted and suitable for agricultural and recreational use. The CWA regulates pollutant discharges from point sources (those coming from the end of a pipe) and non-point sources (run-off from agricultural fields) in rural areas. This act encourages state and local agencies to develop plans for protecting groundwater.

2. *The Safe Drinking Water Act, (SDWA)*

   The purpose of the SDWA is to assure that the drinking water from public water systems is safe. To accomplish this, EPA is authorized to set up uniform water quality standards (Maximum Contaminant Levels) for drinking water, to establish standards for the control of underground injection of wastes, and to designate aquifers as the sole source of drinking water in specific areas.

   The law requires creation of a groundwater protection program, and gives EPA power to order those who contaminate drinking water to provide an alternate supply that is clean.

3. *The Resource Conservation and Recovery Act, (RCRA)*

   This act provides "cradle to grave" management of hazardous wastes by regulating their generation, transportation, treatment, storage, and disposal. RCRA encourages states to develop environmentally sound methods of solid waste disposal. It establishes resource conservation as the preferred solid waste management approach. RCRA sets national standards for management of hazardous wastes. These standards are applicable to those who generate and transport hazardous wastes and to the owners and operators of hazardous waste treatment, storage, and disposal facilities.

4. *The Toxic Substances Control Act, (TSCA)*

   This law assures that chemicals will be evaluated before use to make sure they pose no unnecessary risk to health or the environment. TSCA regulates the manufacture, processing, and disposal of new and existing chemicals that may be toxic to people and the environment. It requires manufacturers and distributors to keep inventories of certain chemicals. This act indirectly protects groundwater by controlling potential contaminants.

5. ***The Comprehensive Environmental Response, Compensation, & Liability Act, (CERCLA)***

   This act establishes a trust fund (Superfund) for financing government cleanup of abandoned hazardous waste sites and emergency cleanup of hazardous substances released into the environment. Groundwater contamination is a major factor in designating a site as a SUPERFUND site.

6. ***The Federal Food, Drug, & Cosmetic Act (FFDCA)***

   This act provides regulatory authority to assure the safety of chemicals used in food, drugs, and cosmetics. This act authorizes EPA to set tolerances, or legal limits, for pesticide residues in raw agricultural commodities, processed foods, and animal feeds. This act established the concept of Health Guidance Levels (HGLs) for agricultural chemicals in groundwater.

7. ***The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)***

   FIFRA largely controls the pesticide industry and agricultural pesticide uses by requiring registration and classification of all pesticides. It calls for the cancellation or suspension of products having adverse effects on the environment (including groundwater). Groundwater advisory statements have been added to some pesticide labels. These statements contain precautions for using pesticides that pose a risk to groundwater.

Federal laws are supported by additional laws at the state and local level. Many state and local laws restrict the use of pesticides considered a threat to groundwater. Some of these laws are more restrictive than federal laws. For this reason, it is important to be aware of and follow all federal, state, and local laws. These laws apply to anyone using pesticides. Pesticide applicators are liable for damages and can be fined or imprisoned for applying pesticides illegally.

Under the laws, pesticides can be removed from the market and from use by growers. To keep pesticides on the market, all pesticides must be applied in a manner consistent with their labels and all applicable federal, state, and local laws.

An effective way to ensure that groundwater is protected while pesticides are applied is to follow the label. More and more pesticide labels include guidelines and conditions of use when the pesticides pose a risk to groundwater.

Stay within the law, follow pesticide label directions and apply pesticides in a safe and cautious manner. This protects the applicator and the environment.

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